GB04/4854

INVESTOR IN PEOPLE

The Patent Office
Concept House
Cardiff Road
Newport
South Wales
NP10 8QQ

REC'D 2 0 DEC 2004
WIPO PCT

I, the undersigned, being an officer duly authorised in accordance with Section 74(1) and (4) of the Deregulation & Contracting Out Act 1994, to sign and issue certificates on behalf of the Comptroller-General, hereby certify that annexed hereto is a true copy of the documents as originally filed in connection with the patent application identified therein.

In accordance with the Patents (Companies Re-registration) Rules 1982, if a company named in this certificate and any accompanying documents has re-registered under the Companies Act 1980 with the same name as that with which it was registered immediately before re-registration save for the substitution as, or inclusion as, the last part of the name of the words "public limited company" or their equivalents in Welsh, references to the name of the company in this certificate and any accompanying documents shall be treated as references to the name with which it is so re-registered.

In accordance with the rules, the words "public limited company" may be replaced by p.l.c., plc, P.L.C. or PLC.

Re-registration under the Companies Act does not constitute a new legal entity but merely subjects the company to certain additional company law rules.

Signed

Dated 1 December 2004

PRIORITY DOCUMENT
SUBMITTED OR TRANSMITTED IN COMPLIANCE WITH RULE 17.1(a) OR (b)

Pa[illegible]ts Form 1/77

Patents Act 1977
(Rule 16)

The Patent Office

23DEC03 E861621-1 D00393
P01/7700 0.00-0329783.5 NONE

1/77

Request for grant of a patent

(See the notes on the back of this form. You can also get an explanatory leaflet from the Patent Office to help you fill in this form)

THE PATENT OFFICE
J
23 DEC 2003
NEWPORT

The Patent Office

Cardiff Road
Newport
South Wales
NP10 8QQ

1. Your reference — 2003P17475 GB / R76 / CF / GD

2. Patent application number *(The Patent Office will fill in this part)* — 23 DEC 2003 — 0329783.5

3. Full name, address and postcode of the or of each applicant *(underline all surnames)*

Roke Manor Research Limited
Roke Manor, Old Salisbury Lane
Romsey, Hampshire SO51 0ZN

Patents ADP number *(if you know it)* — 05615455007

If the applicant is a corporate body, give the country/state of its incorporation — UNITED KINGDOM

4. Title of the invention — TDD for Satcom Application

5. Name of your agent *(if you have one)*

"Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*

Siemens plc
Intellectual Property Department
The Lodge, Roke Manor
Romsey, Hampshire SO51 0ZN

Patents ADP number *(if you know it)* — 04095873005

6. Priority: Complete this section if you are declaring priority from one or more earlier patent applications, filed in the last 12 months.

Country	Priority application number *(if you know it)*	Date of filing *(day / month / year)*

7. Divisionals, etc: Complete this section only if this application is a divisional application or resulted from an entitlement dispute *(see note f)*.

8. Is a Patents Form 7/77 (Statement of inventorship and of right to grant of a patent) required in support of this request? — Yes

Answer YES if:
a) any applicant named in part 3 is not an inventor, or
b) there is an inventor who is not named as an applicant, or
c) any named applicant is a corporate body.

IDNR: 7100 / V: 03-1.01 / B: Val

The Patent Office

1/77

Otherwise, answer NO (see note d).

9. Accompanying documents: A patent application must include a description of the invention. Not counting duplicates, please enter the number of pages of each item accompanying this form.

Continuation sheets of this form	~~11~~ 0
Description	~~0~~ 11
Claim *(s)*	0
Abstract	0
Drawing *(s)*	

10. If you are also filing any of the following, state how many against each item.

Priority documents	
Translation of priority documents	
Statement of inventorship and right to grant a patent *(Patents Form 7/77)*	1
Request for preliminary examination and search *(Patents Form 9/77)*	
Request for substantive examination *(Patents Form 10/77)*	
Any other documents *(please specify)*	

11. I/We request the grant of a patent on the basis of this application

Signature	Date
C French Clive French Chartered Patent Agent	22.12.2003

12. Name and daytime telephone number of Person to contact in the United Kingdom — Clive French — + 44 1794 83 3573

IDNR: 7100 / V: 03-1.01 / B: Val

TDD for Satcom Application

1 Summary

Time Division Duplex (TDD) could greatly simplify the hardware of satellites by eliminating the complex, heavy and costly diplexer filters required to facilitate the use of Frequency Division Duplex (FDD). This, in turn, would allow more complex RF structures to be implemented, including the use of larger numbers of elements in phased array antenna structures.

It is proposed to implement TDD in combination with Time Division Multiple Access (TDMA) in a novel way where switching between uplink and downlink happens following transmission / reception for individual users – Thus instead of transmitting all users' downlinks followed by all users' uplinks, the uplink and downlink time slots are interleaved. The slot time is very short (order 100 μs) compared with the round trip propagation delay. The up and downlink time slots are assigned independently to avoid terminals being required to receive and transmit at the same time and to maximise the range between interfering terminals on the ground. Thus, timing is synchronous at the satellite but appears arbitrary on the ground.

A simulation has been written to evaluate the potential for minimising interference and the available capacity. The results indicate that 100% capacity (i.e. no wasted time slots) is achievable with low interference on the ground.

A method for providing control channels has also been determined. This takes up two channels. Thus for a system based on 100 channels the overhead is only 2%. With 100 μs time slots the TDMA frame length would be 20 ms for 100 hundred channels. Thus the marginal impact on service delay (given 240 ms round trip satellite delay) is negligible.

Interference between satellites is acceptable for three satellite global coverage. It is possible to use favourable synchronisation to avoid interference between adjacent satellites at shorter range.

It is assumed that satellite navigation is used to provide the locations of the terminals. This is used to assist in the setting of timing advance (e.g. for using the random access channel). The locations are also relayed to the satellite so that it can use them to assist in setting up non interfering slot allocations.

2 Background and Technical Problem

It has been suggested that the use of Time Division Duplex (TDD) could greatly simplify the hardware of satellites by eliminating the complex, heavy and costly diplexer filters required to facilitate the use of Frequency Division Duplex (FDD). This, in turn, would allow more complex RF structures to be implemented, including the use of larger numbers of elements in phased array antenna structures.

Traditionally, the use of TDD has been associated with short to medium range terrestrial links where the propagation delays can be kept small in comparison with the length of the frames for TDD operation. This has been a requirement because conventional wisdom was that the TDD

frames needed to incorporate guard periods equal to the maximum round trip propagation delay in order to avoid interference between uplink and downlink under worst case conditions.

The above constraint would clearly be prohibitive in a satellite application given a minimum round trip delay of order 240 ms. Thus it is necessary to re-think concepts for TDD in a satellite context to allow operation with high efficiency (minimal guard time) *and* low marginal delay (short TDD frame).

3 Proposed Outline Technical Solution

In several applications such as DECT, the use of TDD has been combined with time division multiple access (TDMA). By applying these technologies together and making some additional changes it can be shown that the above requirements can, to a large degree, be met.

Consider a simple TDD scheme. The satellite round trip propagation delay being large, it is highly desirable that any physical layer related delays do not add to this significantly. For this reason the TDD frame length should be chosen to be a fraction of the propagation delay. Suppose the one way propagation delay is exactly five times the frame length. The situation is illustrated in Figure 1.

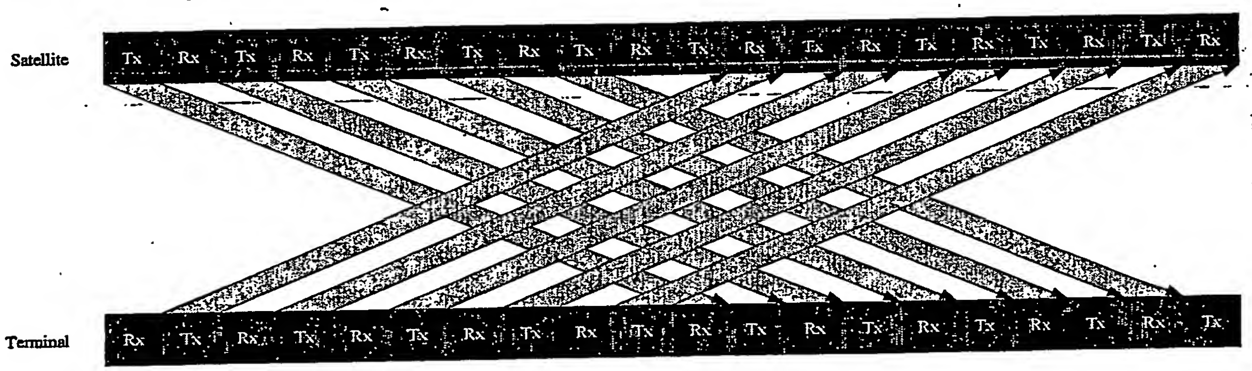

Figure 1 Basic TDD – Ideal Timing

In this case the situation is ideal as every satellite transmission coincides exactly with a terminal receive time slot and vice versa. However, now consider the case where the one way propagation delay is 4.75 times the frame length. This is illustrated in Figure 2

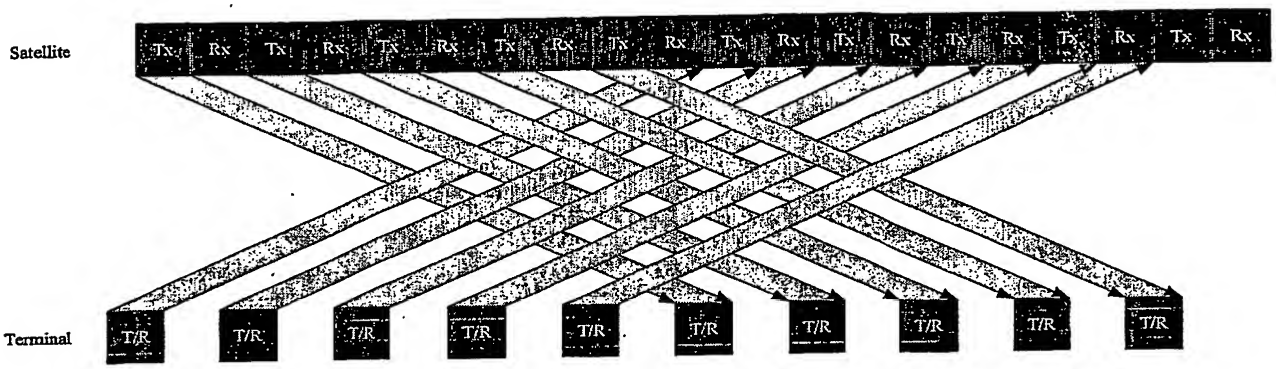

Figure 2 Basic TDD – Worst Case Timing

In this case the timing established by the satellite forces the terminals to receive and transmit at the same time. This is only possible if two separate frequencies are used which defeats much of the object. Half of the time is wasted altogether and the other time is unusable.

The above situation could be alleviated by sharing the timing shifts between the satellite and the terminal so that at least some of the time is usable. However, this leave the capacity effectively reduced to 50%. The approach is shown in Figure 3

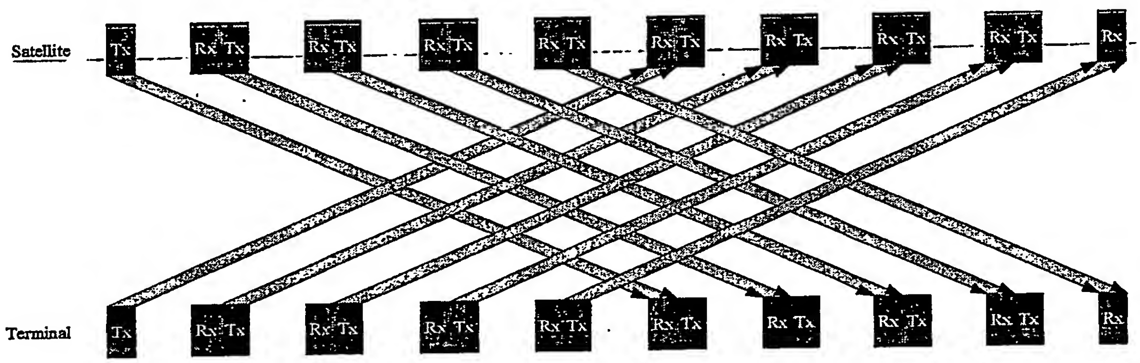

Figure 3 Basic TDD – Distributed Timing

The introduction of TDMA changes the situation considerably. The case for ideal timing with four slot TDMA is shown in Figure 4.

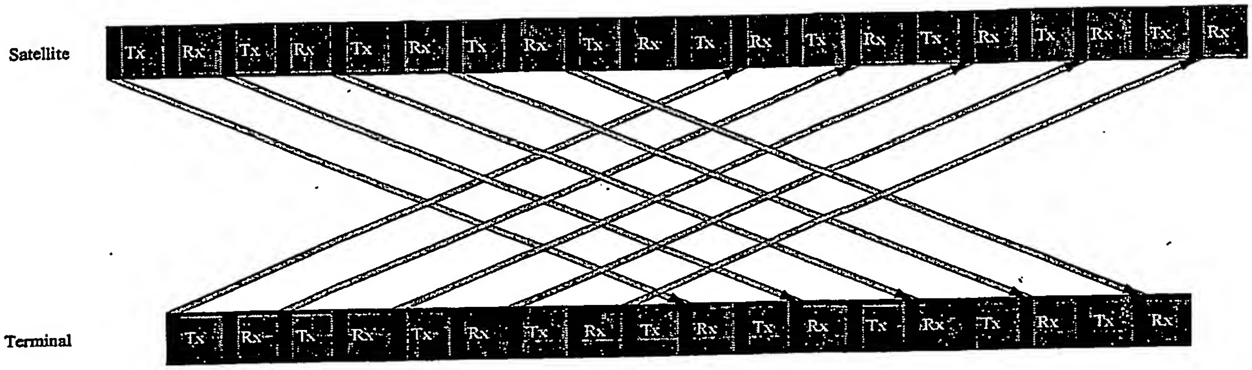

Figure 4 TDD/TDMA – Ideal Timing

Here the first slot is used for both uplink and downlink. The situation is not dissimilar to that shown in Figure 1 except that the transmission and reception times are shorter. If we now look at the situation where the one way propagation delay is 4.75 times the frame length this is as shown in Figure 5.

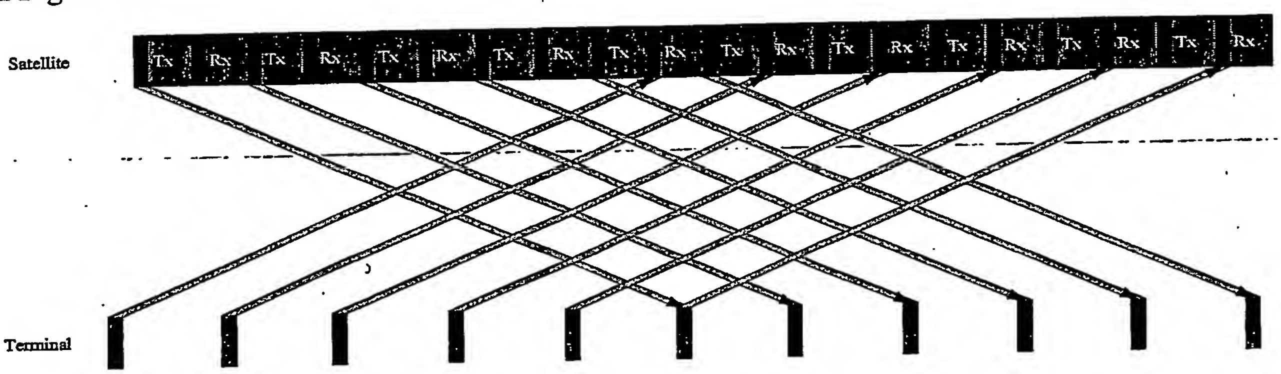

Figure 5 TDD/TDMA – Worst Case Timing

Here we see, in the same way as for Figure 2, that the terminal needs to transmit and receive at the same time. However, with TDMA we have additional flexibility to change the timing to avoid such conflicts. This is illustrated in Figure 6.

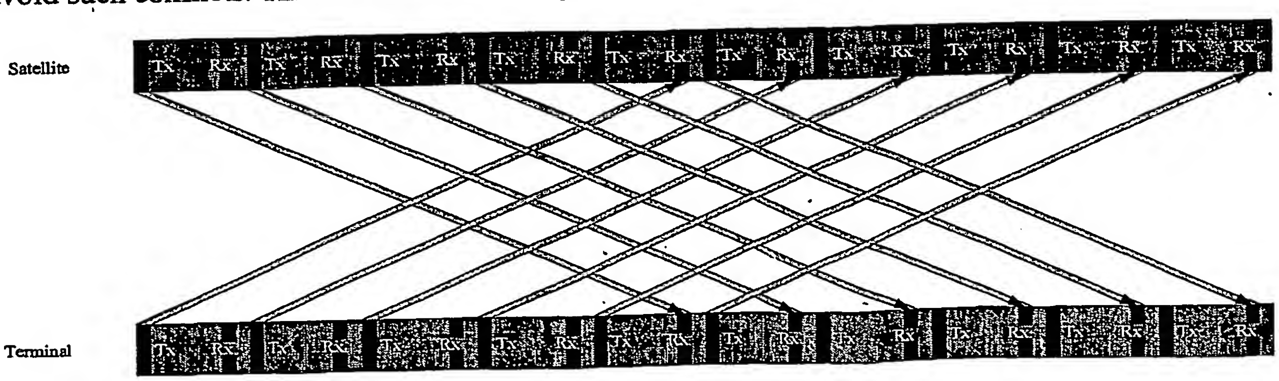

Figure 6 TDD/TDMA – Worst Case Timing – Offset TDD

The above approach, whilst solving the problem is relatively inflexible. At this stage we introduce a novel concept:- *Reversed TDD/TDMA*. In this approach the innermost switching is the TDD switching and the outermost is the TDMA switching. In this case the structure is essentially the same as in Figure 1 except that the source and destinations from successive time slots are different.

Consider the case where we have 4 TDMA channels: A, B, C & D. *Reversed TDD/TDMA* for this case is shown in Figure 7.

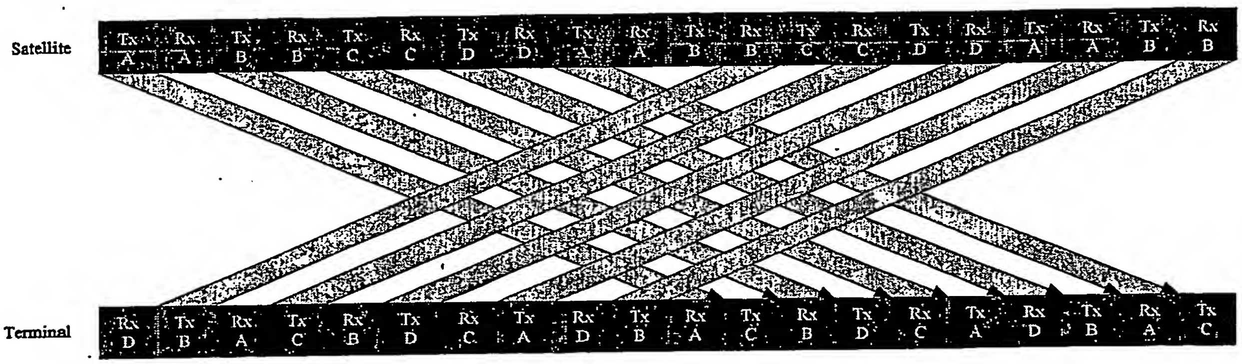

Figure 7 Reversed TDD/TDMA – Best Case

Here we have downlink followed by uplink time slots at the satellite for each successive channel. For the terminals, for simplicity we assume that all are at the same range to the satellite. Nevertheless, because of the large propagation delay, the uplink and downlink slots have become scrambled, but this is of no consequence.

If we now consider the case where the propagation delay is the worst case then we see a similar situation to Figure 2 with an important difference. The situation is illustrated in Figure 8

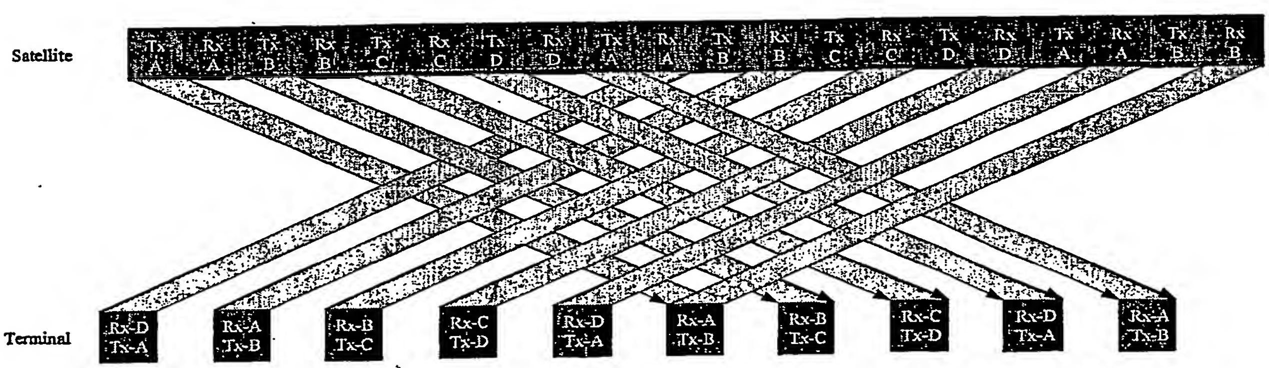

Figure 8 Reversed TDD/TDMA – Worst Case

Here we see that, as before, transmission and reception is required on the earth at the same time. However, these requirements are *not at the same place*. Thus, for example, terminal D must

receive while terminal A is transmitting. If the range between these is large enough then the interference path will be negligible so this will be possible. Moreover, the order of the uplink time slots may be scrambled so as to maximise the distance between mutually interfering terminals.

In practice the terminals will be spread over an area large enough such that the propagation delays to the satellite will vary considerably – i.e. by many time slots. Far from being a problem this effectively randomises the interference and availability of uplink time slots that do not overlap with the corresponding downlink time slot.

The operation, then, is as follows. All timing is synchronous at the satellite but the timings on the ground depend on the propagation delays. Thus terminals are set to receive at the point when their time slot reaches their location. They transmit at the time necessary to ensure that their signal is received *into* the allocated uplink time slot at the satellite.

4 Simulation

A simulation was written to evaluate the performance of such a system. The operation of the simulation was as follows...

- A geostationary satellite was positioned above a point over the equator.
- A coverage area with circular perimeter was identified directly underneath the satellite. Initially this area was the maximum that gave satellite visibility (satellite elevation 0° at perimeter)
- A fixed number of terminals was deployed randomly with uniform distribution over the ground
- The great circle distances between all terminal pairs were computed
- Downlink time slots were assigned arbitrarily to each terminal
- Uplink time slots were assigned initially in the same order as the downlink time slots but with provision for some slots to be shifted if they require a terminal to have overlapped receive and transmit times.

The distances between terminals were used to determine any cases where one terminal's transmission, delayed by the propagation time, overlapped with another terminal's reception time. For those cases, the distances between terminals were noted.

A simulation was run for 100 terminals, with a slot length of 100 μs. Surface plots give an indication of the effect – see Figure 9.

4. Rank the terminals in order from the terminal that will would have the worst interference if using its worst time slot, to the terminal that would have the least worst interference if using its worst time slot

5. Starting with the worst terminal, assign each terminal the best available time slot. In deciding on available time slots ignore any time slot resulting in the terminal having overlapped receive and transmit times.

This algorithm as applied to the above case (actual terminal positions). The interference relationships are shown below. As can be seen there are far fewer.

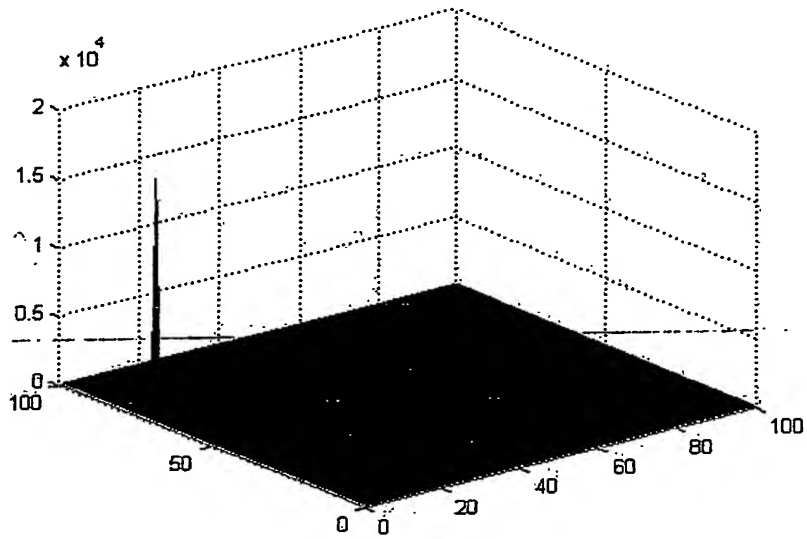

Figure 10 Optimised Interference Relationships – Maximum Coverage

The minimum range to an interferer is now 2,770 km. This represents an improvement by a factor of over 8:1.

Given the ranges available without optimisation this improvement may seem academic. However, as stated earlier, one of the purposes of using TDD is greater to facilitate the use of phase array antennas. This will allow spot beams. It will be desired to use all time slots within a spot beam coverage area and this area will be far smaller than the entire footprint of the geostationary satellite. For example, we might have a footprint of about 60 km. The results for a typical scenario are shown in Figure 11.

The minimum distance is now 51.7 km. We see that the minimum distance is a significant fraction of the diameter of the cell.

The above results are only examples. To obtain more statistically significant results the simulation was run 1,000 times with different random positions for the terminals. The cumulative distributions of minimum range in km for both with and without the optimisation are plotted in Figure 13

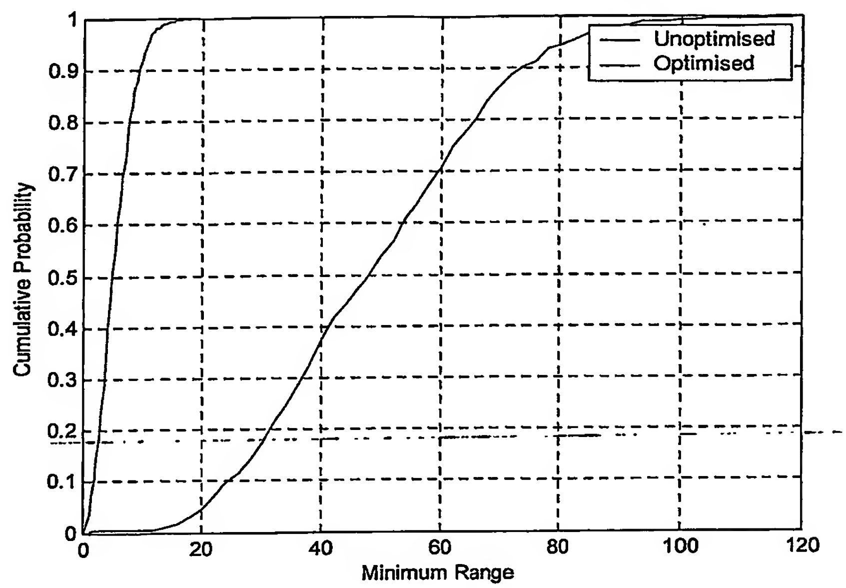

Figure 13 Cumulative Distribution of Minimum Distance (km)

We can see that the optimised case is significantly better than the un-optimised case. There are a small number of cases where the range may be unacceptable. Further improvement of the algorithm is expected to deal with these cases. It should also be noted that the cell size is very small so this represents a worse than worst case situation. A single satellite would need over 15,000 spot beams this to cover 1/3 of the earth! Even allowing for covering land masses only, this still represents a huge number.

5 Inter Satellite Interference

One potential problem with TDD is that not only can terminals interfere with terminals but satellites with satellites. For the case of 3 geostationary satellites covering the earth this is not a problem because the mutual ranges are greater than the satellite to ground ranges. Specifically, simple geometric considerations show that the worst case (i.e. for terminals on the edge of the coverage region) range ratio is about 1.85:1 corresponding to 5.4 dB in free space. Given the additional effects due to antenna patterns, inter satellite interference will not be a problem

The above conclusion is satisfactory but unfortunate in that it appears to limit operation to cases where there are few satellites. In fact it is possible to bring the satellites closer together by ensuring that the propagation delays between adjacent satellites are whole multiples of the TDD period (i.e. twice the slot period – 200 μs in our example corresponding to multiples of about 6 km). If this is achieved then transmissions from one satellite will arrive completely overlap with transmission slots for its neighbouring satellite. For non neighbouring satellites this relationship will gradually break with increasing neighbour distance because the geometry of a circle will gradually take over. Thus in Figure 14, $D \neq 2d$.

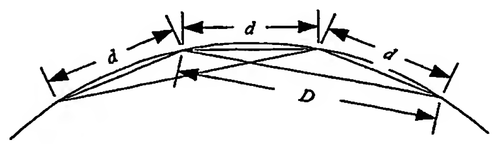

Figure 14 Satellite Distance Geometries

However, if satellites are deployed at relatively short mutual distances then their coverage areas will be reduced on the ground so that their antennas will point more directly downwards leading to greater discrimination between the satellite to ground directions and the satellite to satellite directions.

6 System Issues

It will clearly be necessary to set up calls. This will require a broadcast (BCH) and a random access channel (RACH).

This can be done by allocating a downlink time slot to the broadcast channel and the immediately preceding uplink time slot to the RACH channel. Data will be repeated on the broadcast channel so it will not be essential for every terminal to receive every BCH time slot. However, a terminal could be assigned an uplink time slot that requires it to transmit during the reception period of the BCH time slot. For this reason it is proposed to allocate *two* BCH time slots separated by ½ of a TDMA repeat period. Then *every* terminal will be able to receive one or other BCH time slot.

The other consideration is interference from other terminals using earlier uplink time slots whose propagation delay causes the interference to overlap the BCH reception. This is mitigated by placing the RACH in the previous time slot (we can do this for both BCH time slots so that we have *two* RACH channels). A terminal transmitting on the RACH channel may well interfere with a relatively nearby terminal receiving the BCH channel. However, the load on the RACH channel should be relatively low in any given area so that this interference should arise infrequently, allowing the BCH to be received frequently enough. When the RACH channel is inactive, the minimum range to an interfering terminal (based on 100 μs time slots) would be about 6 km.

PCT/GB2004/004854